Danish Energy Agency

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Electricity & Renewable Energy Authority

EMBASSY OF DENMARK
Hanoi

Grid Modelling of the Vietnamese Power System

Background to Vietnam Energy Outlook Report 2019

July 2019

DETAILED GRID MODELING OF THE VIETNAMESE POWER SYSTEM

This report has been conducted for the **Electricity and Renewable Energy Authority in Vietnam (EREA)** and the **Danish Energy Agency (DEA)**. The report should be cited as *EREA & DEA: Detailed grid modelling of the Vietnamese power system. Background to the Vietnam Energy Outlook Report 2019 (2019)*

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1. Introduction

This project is carried out in parallel with and in support of the project "Capacity building within Balmorel and scenarios", as part of the Development Engagement 1: "Capacity Development for long-range energy sector planning with Electricity and Renewable Energy Agency of Viet Nam", currently being conducted under the Energy Partnership Programme between Viet Nam and Denmark (DEPP).

The main purpose of this project is to contribute to the Energy Outlook Report (EOR) 2019 with a detailed analysis of the transmission grid in Vietnam under a range of scenarios and conditions of the future power system. In particular, the work herein reported aims at:

- **Verifying the Balmorel modelling with respect to the grid representation**. The Balmorel model uses a simplified approach to the transmission grid with, in total, seven transmission lines interconnecting six transmission regions. The capacity of each of these (aggregated) lines must be the practical maximum capacity for secure operation. This capacity may be much smaller than the sum of the technical capacity of the lines between the transmission regions. To verify whether the approach can be applied without overseeing essential restrictions, the PSS/E model is used to model the transmission grid in more detail. This aims at verifying whether any assumptions for capacity between the regions should be revised in Balmorel. Also, the assumption about losses in the transmission system and the investment cost per transmission interface are reviewed.
- **Verifying the grid operation with large shares of wind and solar power**. Two scenarios are tested in the PSS/E model, one where the amount of renewable power is in accordance with the REDS goals and one where the renewable generation is 50% in 2030. Three detailed aspects are considered in the study:
  - Voltage in all grid elements based on snapshots of selected hours, where demand and generation (per plant) are transferred from Balmorel to PSS/E. Over and undervoltage are reported and compared with planning values with +/- 5-10% deviations in relation to normal voltage.
  - Overloading of lines and transformers.
  - N-1 cases are computed: these represent the most critical errors that can occur in the operation of the power system.

2. Methodology

2.1. PSS/E model

Among the power system simulation software used for power development and planning in Vietnam, Power System Simulator for Engineering (PSS/E) is the most commonly used. PSS/E was developed by Siemens PTI, integrating many modules [1], including: (i) Power flow of grid in static state; (ii) Optimal power flow; (iii) Study of symmetric and asymmetrical incidents; (iv) Simulation of the process of electromechanical transition and stable analysis of the system [2], [3].

The elements in the grid such as transmission lines, transformers, generators, capacitors, electric resistors, DC-AC, AC-DC converters, loads at the nodes, are modeled in the form of mathematics. PSS/E uses algebraic methods for equation solving, such as Fixed-Slope decoupled Newton-Raphson, Full Newton-Raphson, Gauss-Seiden, DC Solution to determine solutions of state equations. The set of solution describe the state of the electrical systems, such as phase angle and voltage at the bus; active power and reactive power run on branches (lines, capacitors, series resistance or transformers); power loss on each element and whole power system. For the simulation of electromechanical transients occurring in the power system, PSS/E solves the system of consecutive equations with a short time frame of several milliseconds to observe the evolution of the mode parameters (voltage, frequency, phase angle) when grid incidents occur.

Due to the availability of grid simulation data as input to the PSS/E software in Vietnam, along with the popularity of software, this study proposes to use PSS/E as a tool to simulate grid operation to verify generation development scenarios from Balmorel.

2.2. Grid modelling methodology in this study

The output of the generation from the optimization model Balmorel is used as input to the grid modeling with PSS/E. Balmorel optimizes the hourly output power of each power plant in each region and the loading level of the transmission lines. The most critical dispatching hours (or snapshots) are selected to be simulated in grid operation, in order to check the response of the transmission system. The research methodology follows the steps shown in Figure 1.

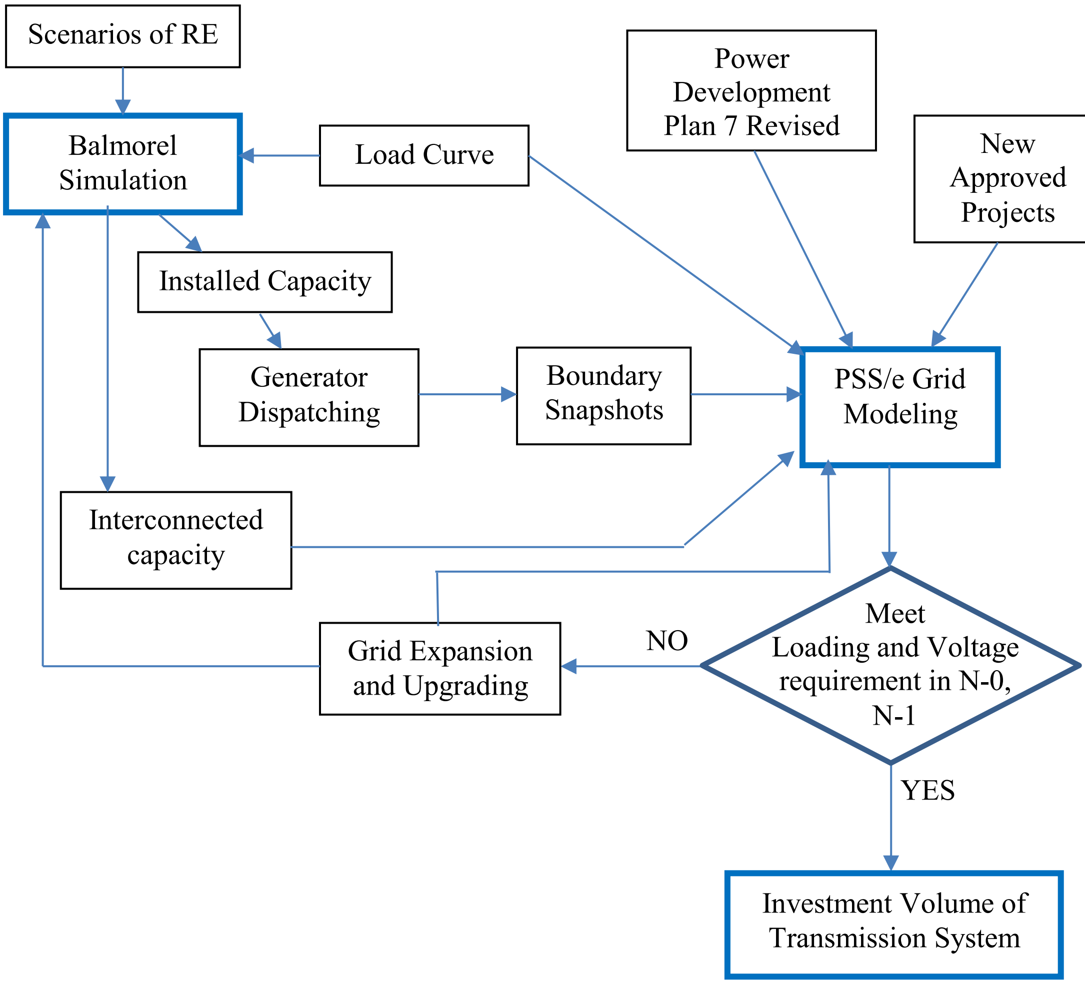

Figure 1. Methodology diagram of steps to perform grid simulation

PDP7 Revised [4], approved on March 2016 is based on three main factors in relation to investment and expansion of the power system: load forecast, generation expansion plan and grid expansion plan. Among the three factors, only the load forecast of PDP7 Revised is relatively close to the actual development as of today, while the generation and grid expansion plan have seen many adjustments, such as: suspended construction of nuclear power plants in Ninh Thuan province; delays for many coal–thermal power plant projects (Long Phu 1, Song Hau 1, ...) or even cancelled plans (Bac Lieu thermal power plant); building of two additional circuits of 500kV North – Central interconnected transmission lines (Vung Ang – Quang Trach – Doc Soi – Pleiku 2) [5]. Policies encouraging renewable energy development led to the expansion of solar and wind power farms in South Central, Central Highlands and Western regions in the last two years. The above mentioned adjustments have been implemented into the grid modeling, with focus on transmission lines and substations.

The connection between the Balmorel generation and transmission expansion model and PSS/E is performed on the basis of harmonizing data on the output power of each unit (or a group of power plants) and the electrical load in the regions for several critical hours of the year. These hours or snapshots are defined based on specific criteria (e.g. highest residual demand or lowest wind and solar generation).

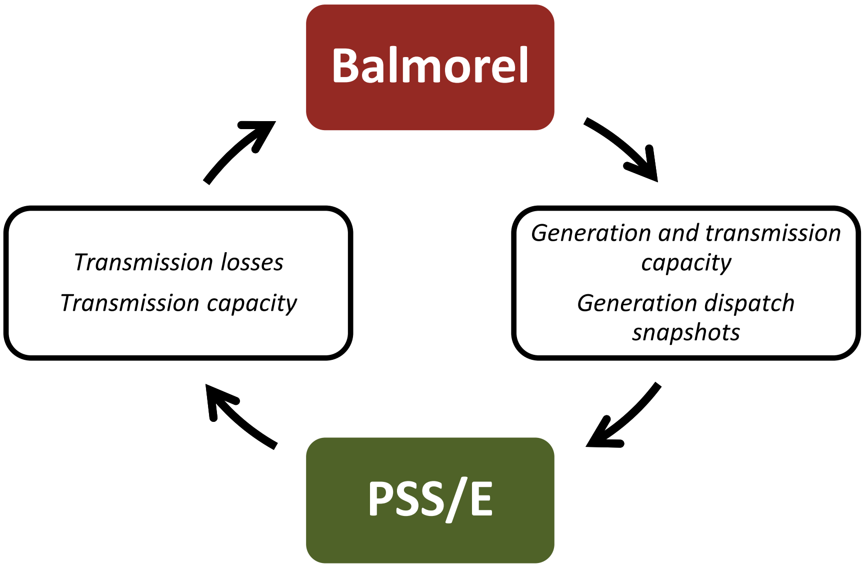

Figure 2. Methodology diagram of interaction between the Balmorel and PSS/E model

For each dispatch snapshot provided by Balmorel, the grid modeling with PSS/E calculates the load levels and voltage requirements of the main elements of the system, such as transmission lines and substations. The simulation grid is built on the basis of the grid represented in PDP7R, with updates on the newest and approved transmission works. First, the check is performed for normal operation condition (N-0) and afterwards for the N-1 contingency cases (N-1). The results are compared to the Grid code standard [6] to check the responsive level of the grid represented in Balmorel. For congested elements, especially interconnected transmission lines, it is necessary to consider alternatives, such as upgrades and expansions of the transmission capacity. The required investment volume of the transmission grid needs to be considered in the generation expansion to reflect the system costs more closely.

3. Scope of grid simulation

The scope of the generation expansion in Balmorel covers the period from today until 2050. In order to have an overall picture of the operation of the power system, the transmission grid needs to be simulated until 2050. However, the current grid database is still quite limited. Transmission lines and substations projects are only approved in the PDP7R until 2030 [4]. There has been no research on the development options of the grid until 2050. Due to the scope of work, data availability and the limited time frame for this project, the calculation of the grid simulation is only calculated for the years 2020 and 2030 with the following purposes:

- Checking the feasibility of the proposed generation expansion scenario for grid operation according to approved planning.
- Checking load level of regional transmission lines for some critical generation operation snapshots; and providing recommendations for upgrading and expanding the interconnected transmission lines.
- Estimating the investment cost for the transmission grid to meet the proposed generation expansion plans.

According to the Grid code [6], the transmission voltage level of Vietnam power system is 500-220kV. According to PDP7 revised, until 2030, the Vietnam transmission power system has only 220-500kV voltage level, while no plans are outlined for other voltage levels (e.g. 750-800 kV AC, 1000 kV AC, HVDC). Therefore, the level 500-220kV is determined as the initial assumption for the simulation in PSS/E. In case the output from Balmorel shows that the power transmission between regions is large enough and if the transmission distance is far enough, higher–voltage transmission solutions (800 kV, 1000 kV) or HVDC will need to be considered in future planning.

The grid with voltages under 110kV voltage level is called distribution grid [7]. Most of renewable energy (RE) sources, such as PV power, wind power etc., are connected to the distribution grid. In this study, the distribution grid will not be simulated in detail. Generation units and demands that are connected to the distribution grid will be equivalent to 220kV bus bars in transmission grid.[1]

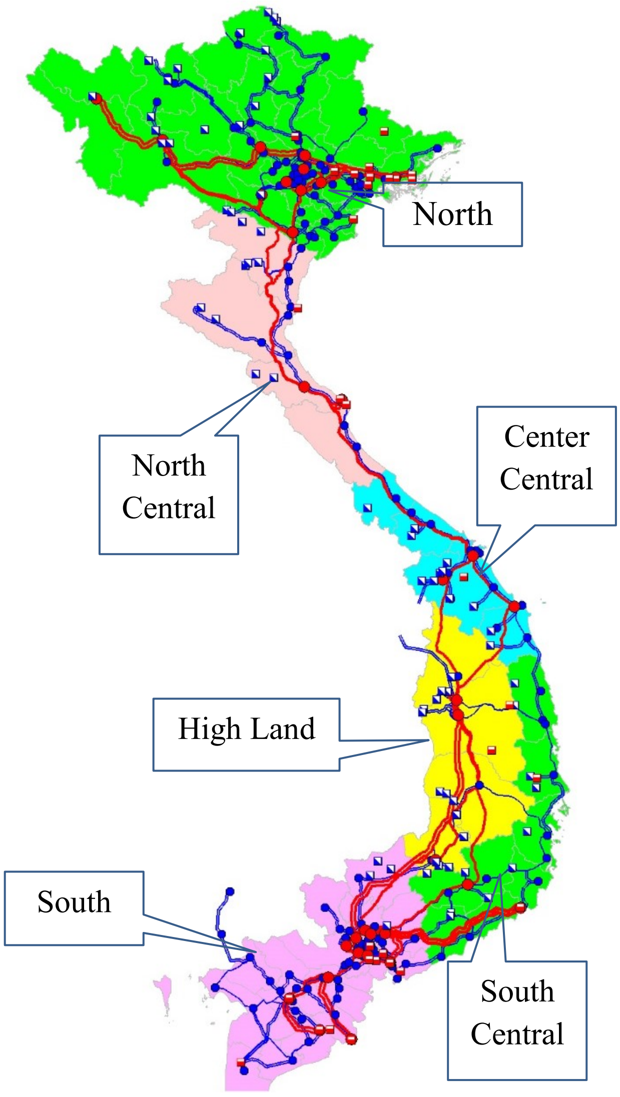

Figure 3. Transmission grid in Vietnam in the 6 transmission regions

[1] If generation nodes under 220kV voltage do not supply enough power to the demand nodes, the power flow will go down from transmission grid (220kV) to distribution grid via 220kV transformers. If generation nodes under 220kV voltage can supply enough power to demand nodes and have excess power, the power flow will go up from distribution grid to transmission grid via 220kV transformers. We simulate under a 220kV grid by flow through 220kV transformers. The power flow on the 220kV – 500kV grid will be relatively similar to full distribution grid simulation.

4. Power system regions

In order to simplify the analysis, based on the characteristics and structure of the grid, the transmission system can be divided into 6 geographical regions, equivalent to the transmission regions used in Balmorel. The details of the regional division of the Vietnamese power system are shown in Figure 3.

The net transfer capacity (NTC) between two regions is the total capacity of the 500-220 kV transmission lines at the interface, considering the N-1 contingency cases. This calculation was made based on the grid configuration in PDP7R (including some updates) for 2020 and used in the Balmorel model as the starting point for the current interconnector capacity between the 6 regions. The transmission flow losses were also calculated in PSS/E for each transmission line and used in the Balmorel model. They were calculated at 80% load.

For two of the scenarios modelled by the Balmorel model, the grid simulation program provides a check of the flow through the interfaces and compares it with the simulation data of the generation plan, as to provide recommendations about the response level of the grid.

5. Input assumptions and harmonization with Balmorel results

5.1. Demand forecast and location of demand nodes in the power system

The demand nodes in the power system are determined based on database of PDP7 revised [4]. The loads are updated based on the Balmorel model, to provide grid operation snapshots, which are the most similar to the results of the Balmorel model. The peak load (Pmax) and the electricity consumption in the regions until 2030 for both scenarios are shown in Table 1 and Table 2.

Table 1. The forecast of Pmax in regions (MW)

No.	Region	PDP7R		Balmorel	
		2020	2030	2020	2030
1	North	16,028	33,644	15,981	31,838
2	North Central	3,322	6,973	3,312	6,598
3	Centre Central	2,773	5,937	2,765	5,618
4	Highland	1,379	2,951	926	1,881
5	South Central	2,600	5,566	2,978	6,050
6	South	20,219	44,524	20,159	42,133
7	**Vietnam**	**42,261**	**90,989**	**41,332**	**84,431**

Table 2. The forecast of electricity consumption in regions (GWh)

No.	Region	PDP7R		Balmorel	
		2020	2030	2020	2030
1	North	93,874	197,044	93,856	186,978
2	North Central	15,878	33,332	15,875	31,629
3	Centre Central	10,352	22,164	10,350	21,032
4	Highland	4,422	9,464	2,978	6,049
5	South Central	9,706	20,780	11,148	22,651
6	South	126,681	278,967	126,657	264,717
7	**Vietnam**	**260,913**	**561,751**	**260,864**	**533,055**

From the above tables, it can be seen that the location of load is unevenly distributed among regions. Power consumption is mainly concentrated in the two extremities of the country. The North accounts for 35% and the South accounts for 50% of the total consumption. However, the favorable locations for the development of coal, gas, LNG, wind and solar power plants are concentrated in low load regions such as North Central, Highlands and South Central. This can put pressure on investment to improve the transmission capacity between regions.

5.2. Location of power sources in transmission grid simulation

One of the outputs of the Balmorel model is the generation capacity for the years in the period of calculation. The transmission region of the investments in new power plants is determined by the Balmorel model. However, the exact location within each region is not a model result. Therefore, one of the important tasks of the grid simulation is to locate the new power plants in the system. This task clearly belongs to the National Power Development Plan and is a relatively complex and difficult task.

However, due to the scope of the grid simulation until 2030 (i.e. the last planning year of the approved PDP7 revised) and due to the load forecast in 2030 not being very different from that forecasted in PDP7 revised (515-523 billion kWh compared to 561 billion kWh in PDP7 revised), the adjustments to the grid configuration in 2030 mainly relate to the adjustment of the power generation mix and the transmission lines (i.e. replacing traditional sources by RE sources).

To construct the transmission grid in 2030 compatible with Balmorel's output, the following data should be added:

- Generation capacity of each region (classification according to fuel type) from the output of Balmorel, including operating time and capacity.
- List of power plants expected to operate in the period 2019-2030 according to PDP7 revised.
- Location of new power plants that were added to the plan in the period of 2019-2030 (additional to PDP7R).

- 500-220kV transmission grid scheme (transmission line and substation) approved in PDP7R.
- Potential position of power sources (classified by fuel type).

According to the review of power generation data of PDP7 revised for the period of 2019- 2030, there will be about 64 traditional power plants (coal thermal, LNG, hydro power plants) in turn operating with total capacity of 60 GW. The locations of these new power plants are almost clearly defined.

For small hydro power sources, there are currently about 222 power plants with total capacity of 3000 MW. According to planning data, which is collected from provincial power plans, the total capacity can reach 7500 MW with 509 plants until 2025. Thus, the location of new small hydropower plants (about 4500 MW) has also been completely identified.

Location of renewable energy sources represents the main difficulty in grid simulation. However, currently there are some advantages as follows:

- Currently, about 100 PV power projects have been approved to provide additional supply, with a total installed capacity of 7200 MWp. The location of these projects has been completely determined.
- There are 500MW of wind power farms (10 projects) approved for supplementation planning, with some of these power plants already put into commercial operation. The location of these projects is also completely determined.

Besides, there are currently about 108 PV power projects (total capacity of 10900 MWp) [8] and 149 wind power projects (total capacity of 14800 MW), which have been located. These projects are preparing an application for investment.

Thus, the total capacity of solar power and wind power sources with a determined location is about 33300 MW (18000MW of PV power and 15300 MW wind power).

The location of power plants with different types of RE sources is determined according to the draft national RE plan until 2030 [9]. Accordingly, until 2030, there will be about 85 power projects from Solid Waste, total capacity of about 830 MW; 100 biomass power projects, total capacity of 3000 MW; 44 geothermal projects, total capacity of about 700 MW.

With the above reviews, until 2030, the total capacity of power plants which has a clearly defined location, reaches about 150 GW (50 GW of existing resources and 100 GW of potential sources).

Distribution of solar and wind power sources implemented in PSS/E is shown in Figure 4.

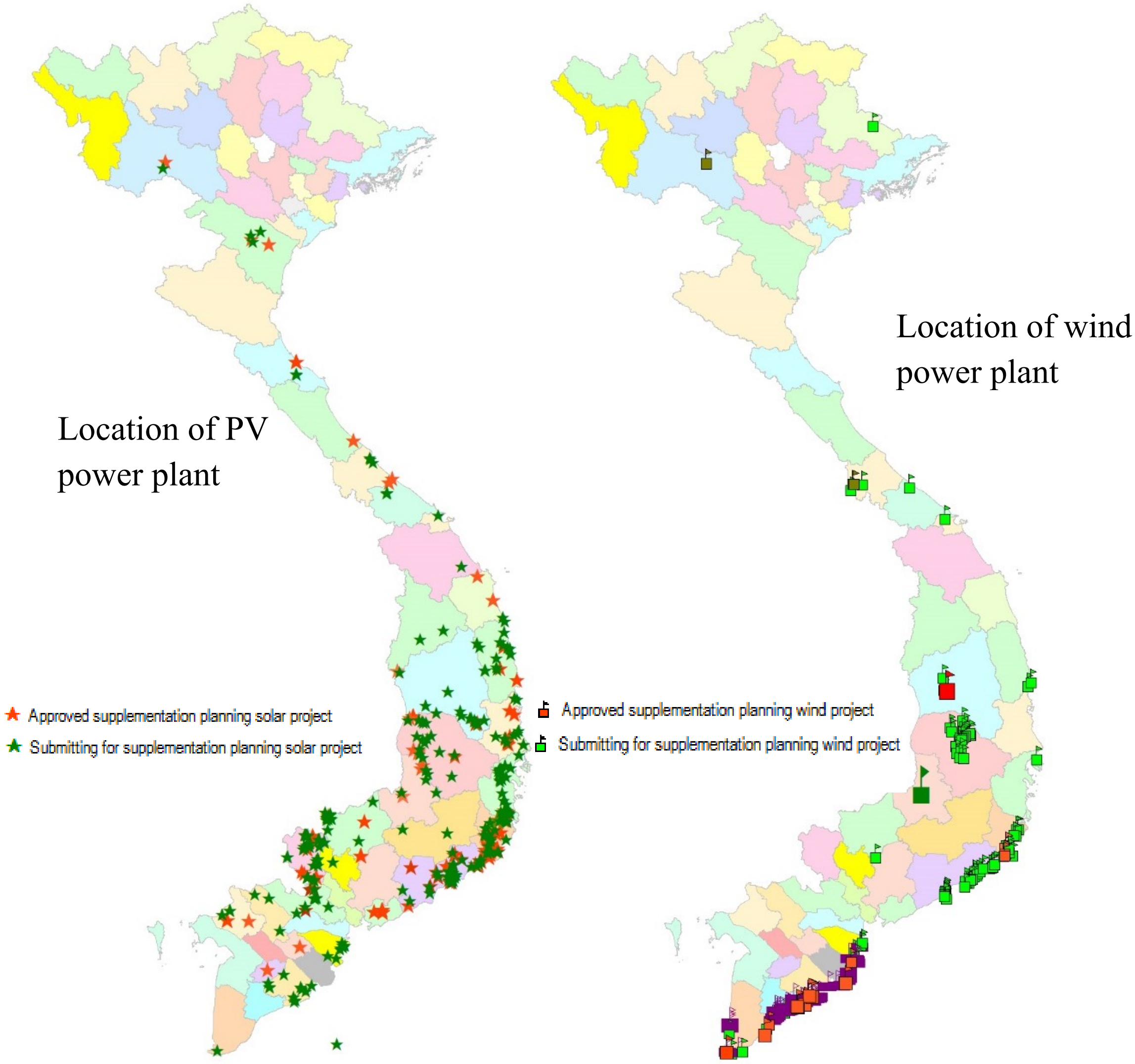

Figure 4. Location of PV solar and wind power plants.

5.3. Other assumptions

Power factor at load nodes (Cosφ):

The voltage on the grid depends very much on the power factor Cosφ at load node. Cosφ usually ranges from 0.9 to 1.0. The lower the Cosφ, the more reactive power the load consumes. This can lead to the lower voltage. Since the power grid simulated in this project only represents equivalent electrical load at 220 kV nodes, it is assumed that Cosφ = 0.98 – i.e. the average compared to the present (0.95-1.0).

Generator terminal voltage:

Traditional generators and modern inverters for wind and solar power can act as voltage control elements on the grid, by controlling the amount of emitting reactive power. However, the output voltage of the generators cannot be set too high or too low and must meet the requirements of the Grid code. In the grid simulation, it is assumed that the terminal voltage of generators varies within +/- 5% of the rated voltage.

Limitation capacity of transmission lines: in this project, the thermal limit of transmission line is used (except for lines over 300 km using the limit capacity according to the condition of power system stability).

Limit capacity of 500/220 kV transformers: it is set according to the rated power of the transformer.

Resistor, resistance of line and transformer parameters (R0, X0, B0): typical parameters on the current transmission grid are used.

6. Calculation scenarios in the transmission grid model

There are around 8760 hours of generation dispatching mix in one year, corresponding to 8760-time steps of load (with approximate hourly accuracy). Therefore, in theory, it would be necessary to observe 8760 hours of power grid simulations in a year to test the ability of the grid to respond to generation dispatching and load at the same time. However, not all 8760 grid operation modes are critical. In the grid simulation of the planning problem, it is often only some of most critical operation modes that are interesting to reduce the calculated volume. If the most critical operation modes are satisfied, the grid can respond well to the remaining operation cases.

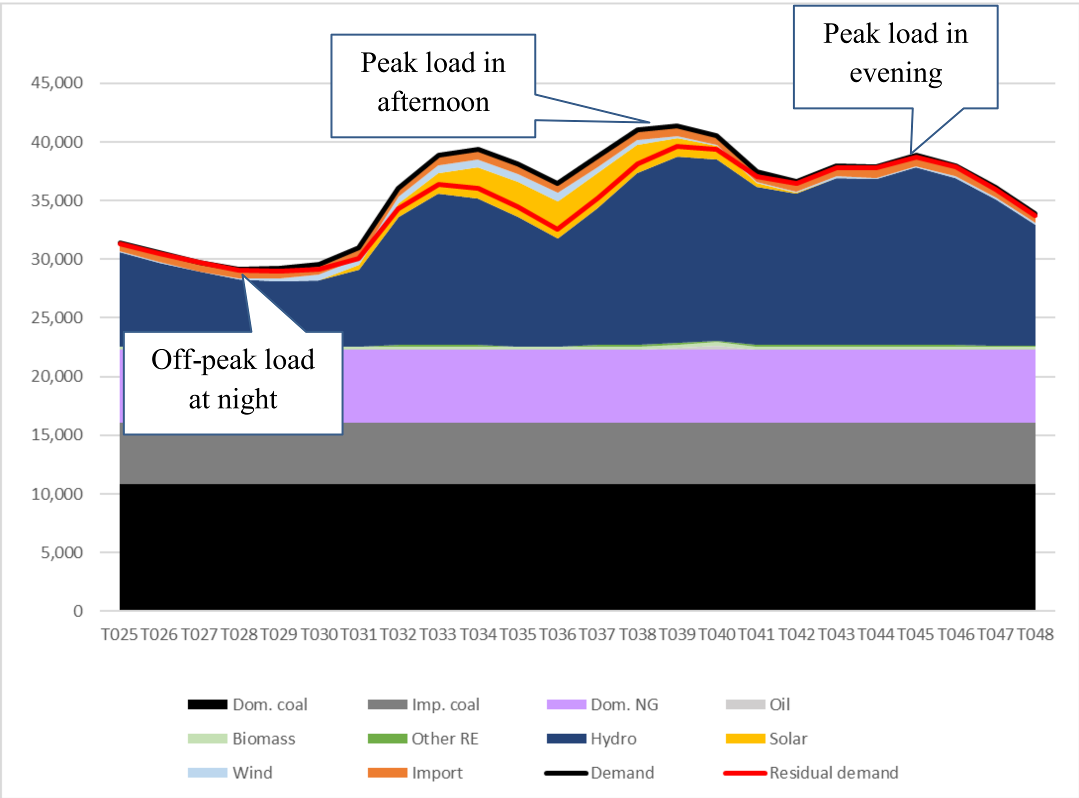

Figure 5. Source operation mode on day with high load in 2020.

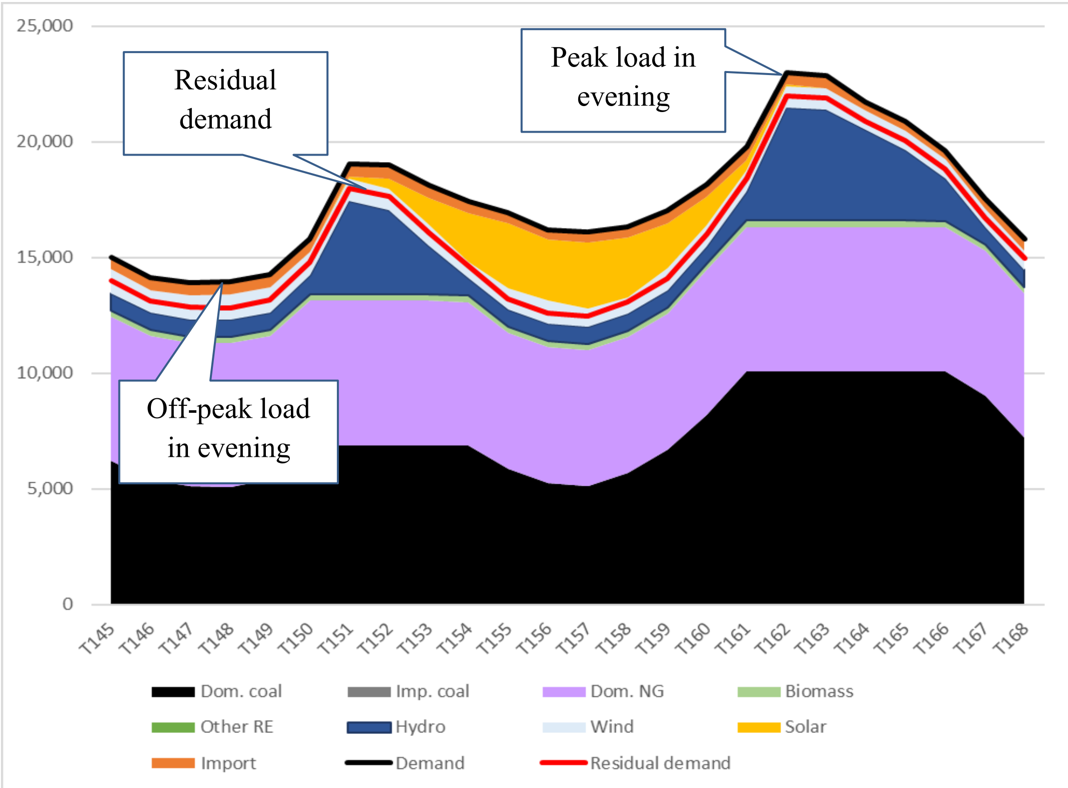

Figure 6. Source operation mode on day with low load in 2020.

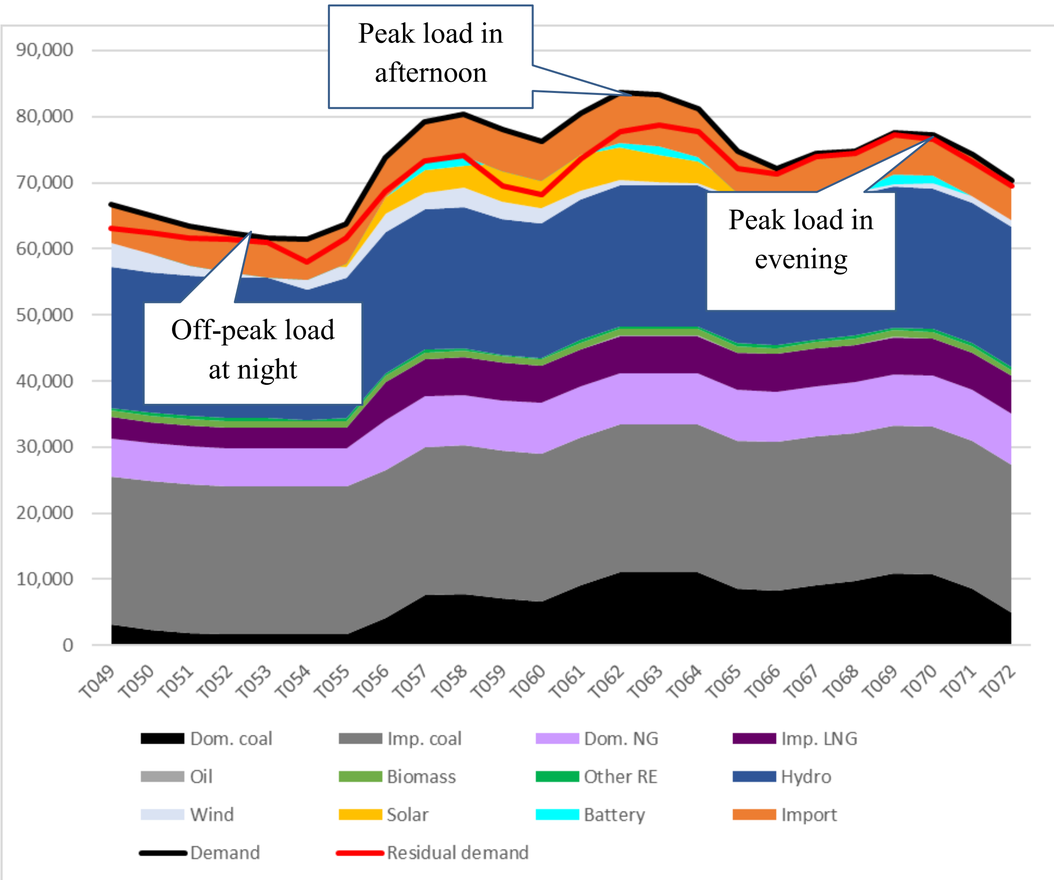

Figure 7. Source operation mode on day with high load in 2030.

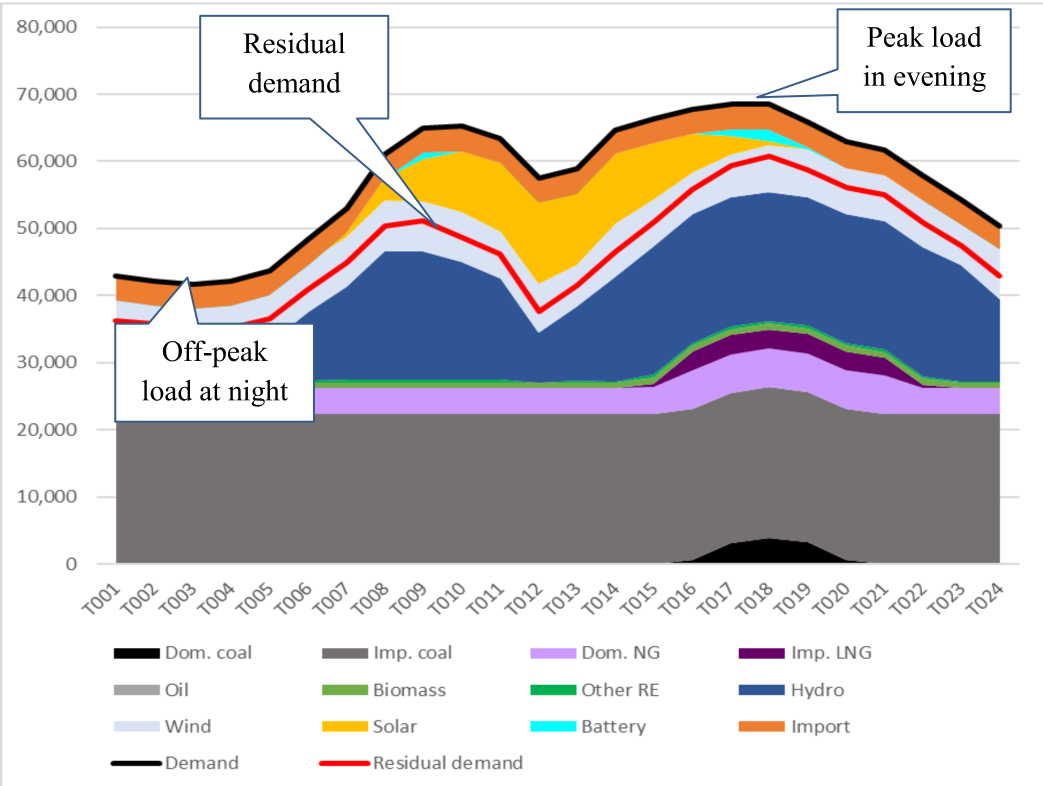

Figure 8. Source operation mode on day with high wind and solar in 2030.

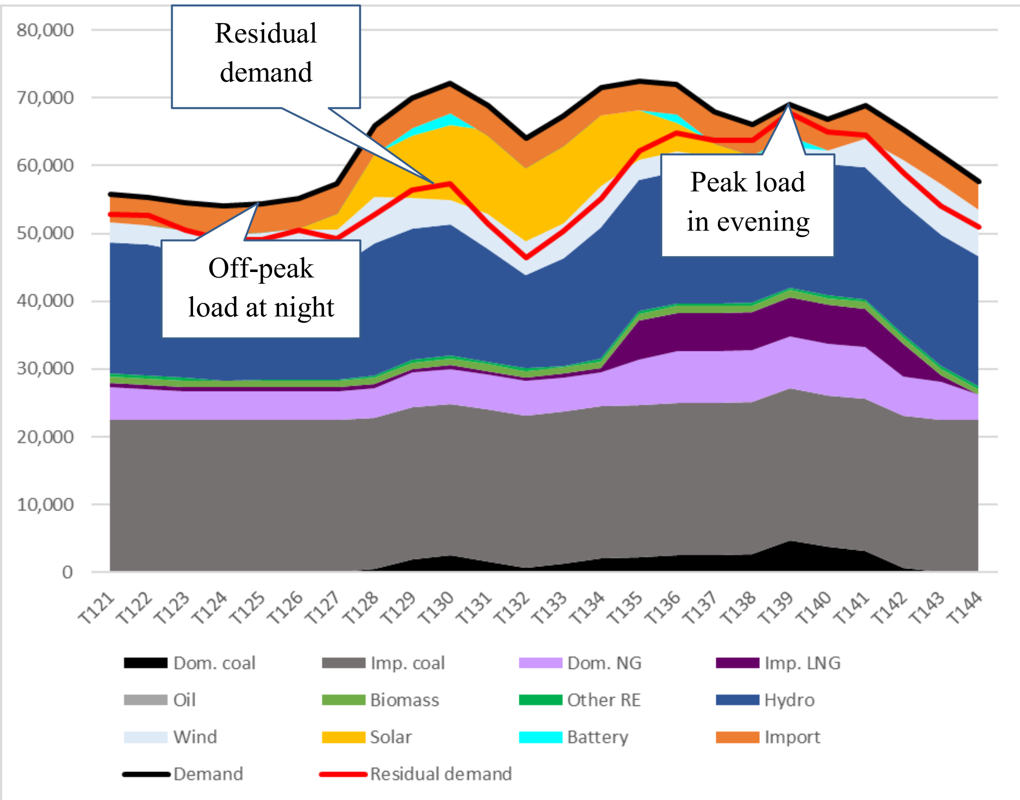

Figure 9. Source operation modes on day with low wind and solar in 2030.

The interesting operation snapshots for the simulation of the load flow in the power system are as follow:

- Highest demand (HD)
- Lowest demand (LD)
- Highest residual demand (HRD)
- Lowest residual demand (LRD)
- Maximum total interconnected transmission capacity (HF)
- Minimum total interconnected transmission capacity (LF)
- Highest Solar and Wind (HWS)
- Lowest Solar and Wind (LWS)

The HD snapshot usually is in the period 10:00-14:00 or 19:00-21:00 [10]. The HD snapshot is used to check the capability of transmission lines in the heaviest load condition. The LD snapshot is the lowest load condition (usually the first days of the lunar year - New Year holidays). In LD snapshot, voltage in the transmission grid is often high. Therefore, the LD snapshot is used to check the voltage in the grid. In some other calculations, the LD snapshot is considered locally to check the possibility of releasing power from coal thermal plants and wind power plants, as this snapshot represents the heaviest operation condition for transmission lines.

At the period 19:00-21:00 in the evening, the load is high while the output power from PV solar is zero. This is the HRD snapshot. This snapshot is used to check the possibility of releasing power from traditional power plants (Coal-thermal, LNG, hydro power plants).

The LRD snapshot represent the condition with maximum output from wind and solar PV power. This snapshot is used to check grid operation when dispatching of traditional sources is lowest; supply grid for battery is in charge mode; and, the possibility of releasing power from wind and PV solar power plants when the output power of these sources is high.

The HF and LF snapshots are used to check the responsiveness of the transmission grid in two states: the highest flow and lowest flow on all interconnections. HF is usually a condition where sources in one region have high output power and transmit to other regions over a large transmission distance. The LF snapshot shows minimum level of transmission between regions to achieve the lowest system cost. If the HF and LF are both high on transmission load for certain lines, this indicates high transmission over a long distance, leading to large transmission losses in the power system. This requires large investment for transmission lines.

The HWS and LWS snapshots correspond to the highest and lowest wind and solar power in the South-Central region. These snapshots are used to assess impact of wind and solar power on the transmission grid.

7. Results of grid simulation corresponding to power generation development scenarios

7.1. Results of grid simulation in 2020

The simulation of the transmission grid calculation in 2020 is hardly meaningful for planning purposes because most of power plants and transmission projects have been constructed. This work is mostly meaningful to verify the dispatching simulation results from Balmorel and to provide recommendations on the operation of the transmissions grid. Especially, there will be significant occurrences of RE sources such as wind and solar power in the Central and Southern regions in 2020.

PSS/E simulated grid operation in 8 snapshots: HD, LD, HRD, LRD, HF, LF, HWS and LWS for the year 2020. The results can be summarized as follows.

Under normal operation conditions (N-0):

- In normal operation, i.e. HD and HWS snapshots, the congestion appeared in some elements which release output power from RE sources in South Central at

HD and HWS. The 500/220kV Vinh Tan substation is 33% overloading. Da Nhim – Duc Trong – Di Linh 220kV transmission line is 3% to 32% overloading. 500/220kV Di Linh substation has 100% load level.

- Some elements of the transmission grid in the North and North Central regions have a high load level in the LWS snapshot (19:00-21:00), as well as some transmission lines from Hoa Binh hydro power plant to Ha Noi, Nho Quan – Thanh Hoa TL.
- Transmission lines and substations have relatively light load level in the LD and LF snapshots.

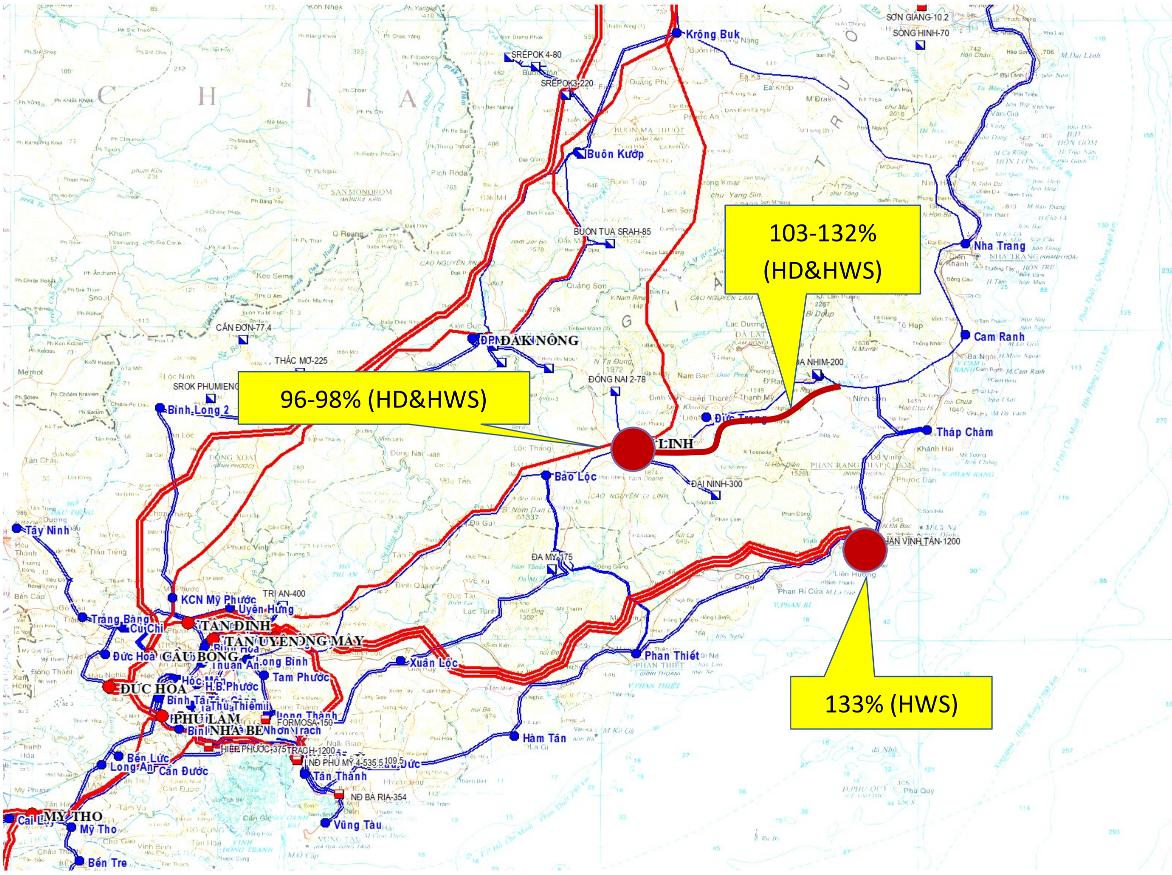

Figure 10. The overloading elements due to releasing output power of RE sources in South Central region.

In the N-1 contingency cases (N-1):

When one element in the transmission grid has contingency, other elements could operate under higher loading or overload in some cases. When N-1 contingency cases make other elements overload, the N-1 criteria are not satisfied. The effect of contingency for all 756 grid elements modelled was tested one by one.

The amount of N-1 contingency cases which result in other elements overloading are summarized for the 8 Balmorel snapshot as follows:

- HD: 63/756 cases (8,3%)
- LD: 3/756 cases (0,4%)
- HRD: 63/756 cases (8,3%)
- LRD: 0/756 cases (0%)
- HF: 30/756 cases (3,9%)
- LF: 1/756 cases (0,1%).
- HWS: 45/756 cases (6,0%)
- LWS: 71/756 cases (9,4%)

Note: The total number of transmission lines and transformers in transmission grid is 756.

The results show that LWS is the snapshot with the highest amount of N-1 criteria not met (highest violation rate). This snapshot has 71 violations (9,4%). The second is HD with 63 violations, accounting for 8,3%. In these snapshots, the system has high load (19:00-21:00), output power of solar sources is zero, transmission lines and substations have high loading level. This leads to overload, when there is N-1 contingency on neighboring element.

In low load snapshots (LD, LF, LRD), the load level of transmission lines and substations is low. The transmission grid can well meet the N-1 criteria. Violation account for 0-0,4%.

The results of the load flow simulation for 8 output snapshots determined by Balmorel for N-0 and N-1 condition show that this result matches the recent study about grid operation in 2020 [11].

The results of the grid simulation also show that some elements in grid would need to be upgraded, such as 500kV Di Linh, Vinh Tan substations, Da Nhim – Duc Trong - Di Linh 220kV transmission line and some transmission lines which release output power from Hoa Binh hydro power plant to Ha Noi. These projects are being implemented and will operate as soon as possible.

7.2. Results of grid simulation in 2030

In order to assess the feasibility of generation plant mobilization results according to Balmorel, PSS/E calculates the power flow of the power system in 2030 for 2 Balmorel power system development scenarios: *C1 RE target* and *RE3 50pct*. In each scenario, 4 snapshots correspond to 4 typical hours in the year selected for simulation, including: HRD, HF, HWS, LWS (characteristics of each snapshot as presented in section 6). The power flow results from PSS/E show the bottlenecks, overload points, thus helping to make recommendations and solutions to reinforce the grid, ensuring the release of power output and net transfer capacity on interfaces. The grid will be reinforced to meet technical criteria in the normal operation condition (N-0) as well as contingency cases (N-1). Main results are presented in the following sections.

7.2.1. *C1 RE Target scenario*

Transmission interfaces:
As explained above, to simplify calculations, Balmorel has divided the system into 6 geographical regions corresponding to 7 transmission interfaces including: North - North Central, North Central - Center Central and Center Central - Highland, Center Central - South Central, Highland - South Central, Highland - South, South Central - South. Net transfer capacity (NTC) of interfaces considering N-1 criteria used in PSS/E is determined by PDP7R [4] in Figure 11:

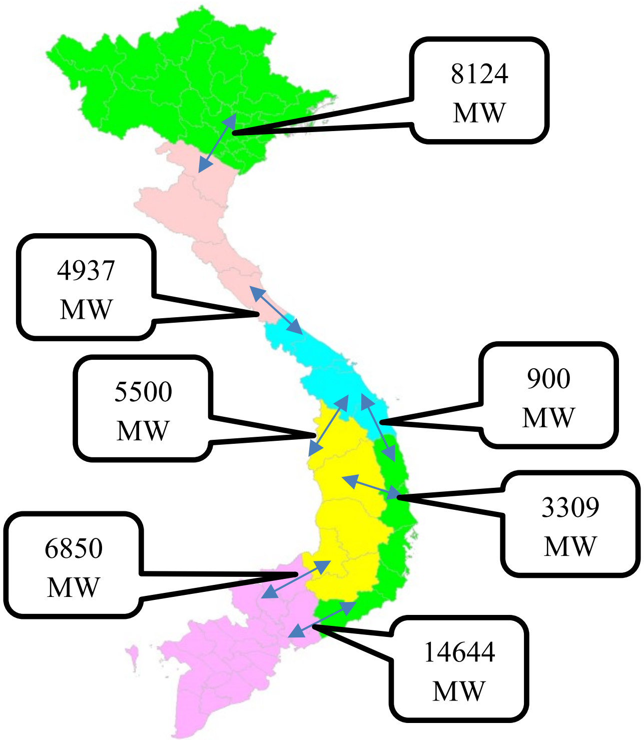

Figure 11. Net transfer capacity of 7 interfaces in 2030

After simulating by PSS/E for 4 snapshots in 2030, for the *C1 RE target* scenario, the main results can be summarized as follows:

Under normal operation conditions (N-0):

In N-0 condition, most interfaces ensure transmission within the allowed range. However, in the HF and LWS snapshots, the Highland - South interface transmits 10212 MW and 7652 MW respectively, exceeding the capacity of 6850 MW. Specially, in the HF snapshot, many transmission lines in Highland - South interface are overloaded such as: Krongbuk - Chon Thanh 500kV line (15% overload), Krongbuk - Tay Ninh 500kV line (18% overload), Xuan Thien Easup - Krongbuk 500kV line (25% overload) and Krongbuk 500kV substation overload heavily (229% overload). Overload occurs mainly due to large concentrated renewable energy sources in the Highland region, which are transmitted to the South load center. The cause of this overload is that the transmission grid of PDP7R in 2015 does not consider the high development of renewable energy sources (wind power, solar power), which has occurred in the last 2 years.

Therefore, this study recommends building a new 500kV substation in Highlands region to gather output power of renewable energy sources and directly transmit it to the Southeast region. At the same time, in order to ensure 10 GW transmission on the Highland – South interface, it is necessary to build at least 3 new 500kV transmission lines from Highland to Southeast with distance of 350-400km. It is possible to consider transmission by HVDC technology in case of difficulties in finding corridors. As the HVDC lines occupy less land area than HVAC lines, they might be more suited in mountainous areas.

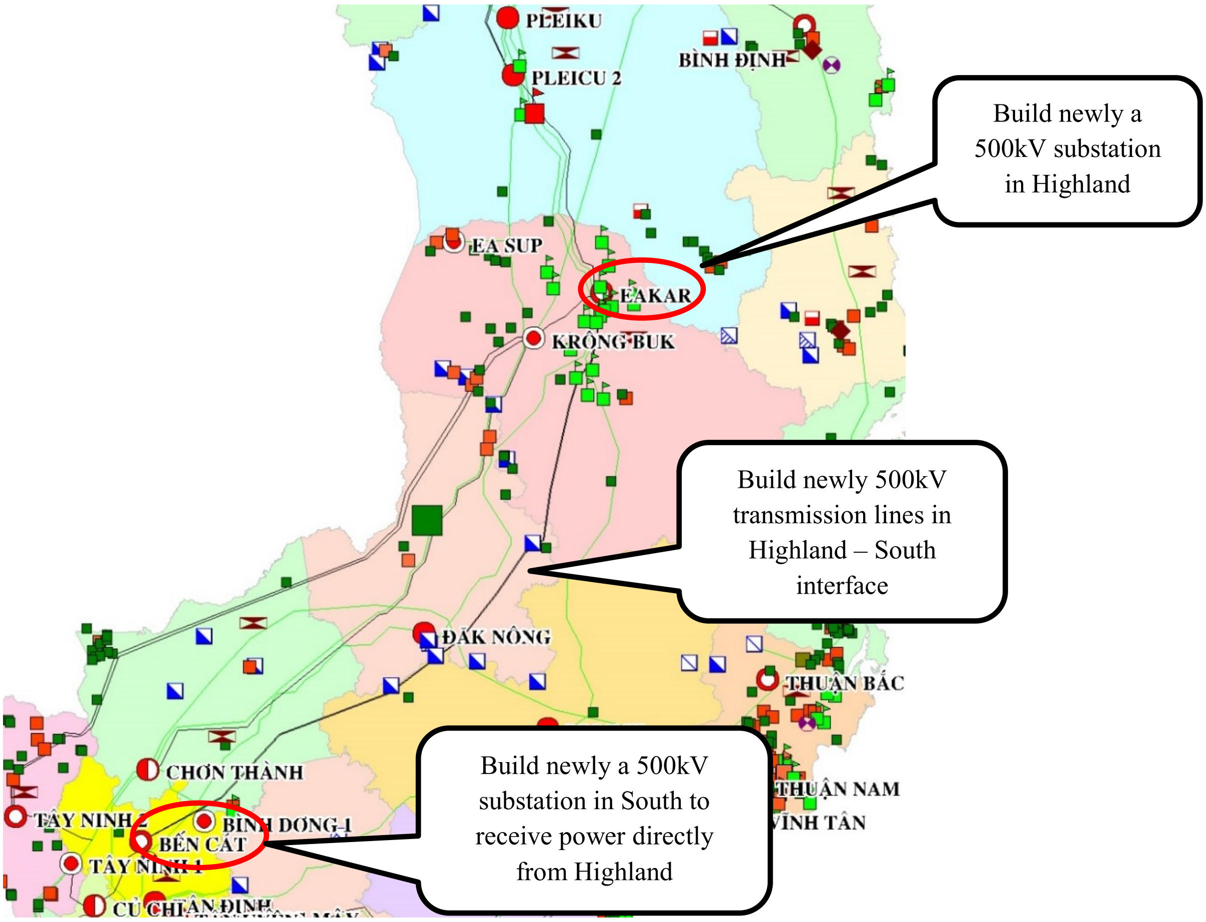

Figure 12. Tay Nguyen – South interface expansion.

In the N-1 contingency cases (N-1):

- Some 220kV transmission lines of South Central - South interface need to improve the limit capacity. Some solutions can be considered such as: raising limit capacity of Da My - Xuan Loc, Bao Loc - Dinh Quan; building newly 2 circuits from Phan Thiet to South.

Internal transmission grid:
Under normal operation conditions (N-0):

- Some overloaded 500kV substations playing an important role in transmitting power of renewable energy are recommended to increase capacity such as: Lai Chau, Thanh My and Doc Soi. In particular, Lai Chau 500 kV substation and Thanh My 500kV substation are important point in transmission small hydropower and imported power sources from Northern Laos and Southern Laos.
- With the new generation development areas, it is proposed to build 500kV substations to transfer transmission capacity to the national power system. For example, the Dien Bien area (in the North) contributes to increasing the purchase of electricity from Laos; Thuan Nam, Hong Liem and Thuan Bac areas (in South Central) contributes to strengthening release of solar power and wind power; the Huong Hoa area (in Center Central) contributes to strengthening the release of wind power in Quang Tri; Bac Lieu area (in South) contributes to strengthening release of wind power in Southwest.
- Towards 220kV, some lines overload such as Hai Duong TPP - Hai Duong, Vung Ang - Formosa in HF snapshot; Phan Ri - Phan Thiet, Cam Ranh - Nha Trang, Thap Cham - Vinh Tan, Da Nhim - Duc Trong - Di Linh in HWS snapshot. These lines need to be upgraded limit capacity by replacing with thermal resistant conductor.

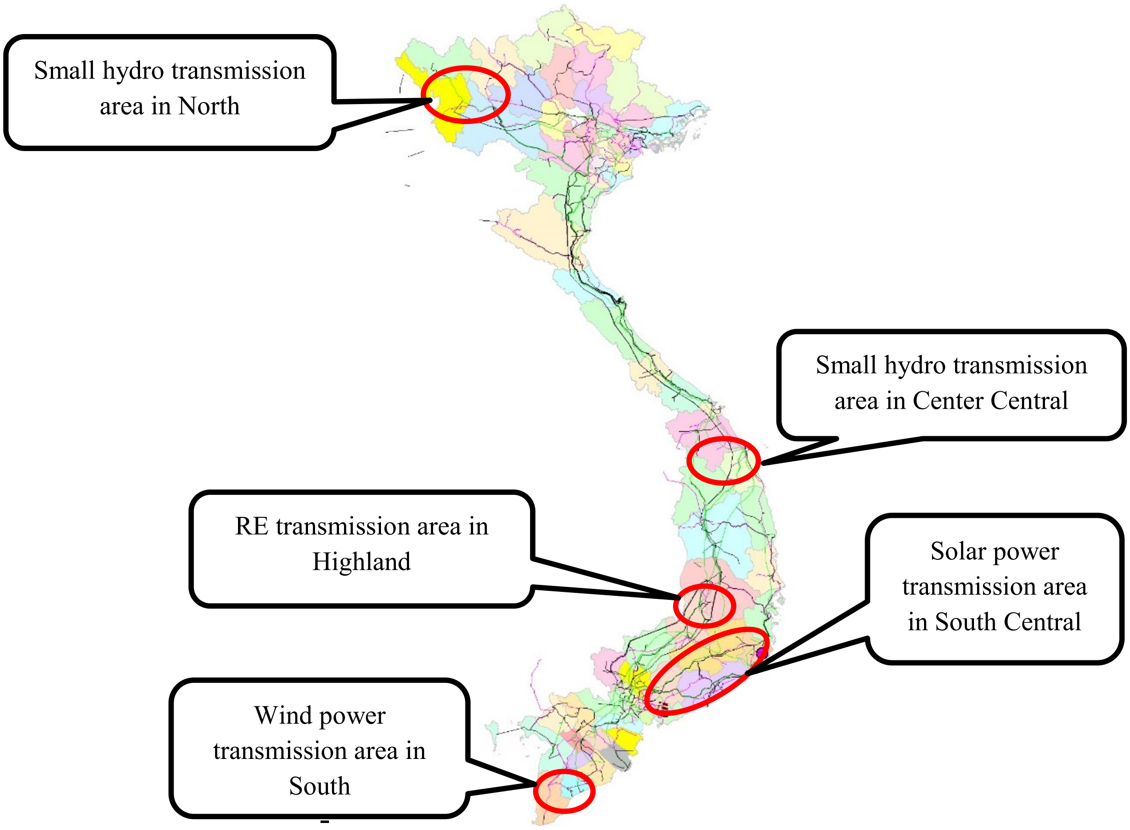

Figure 13. Some congestion areas in transmission grid.

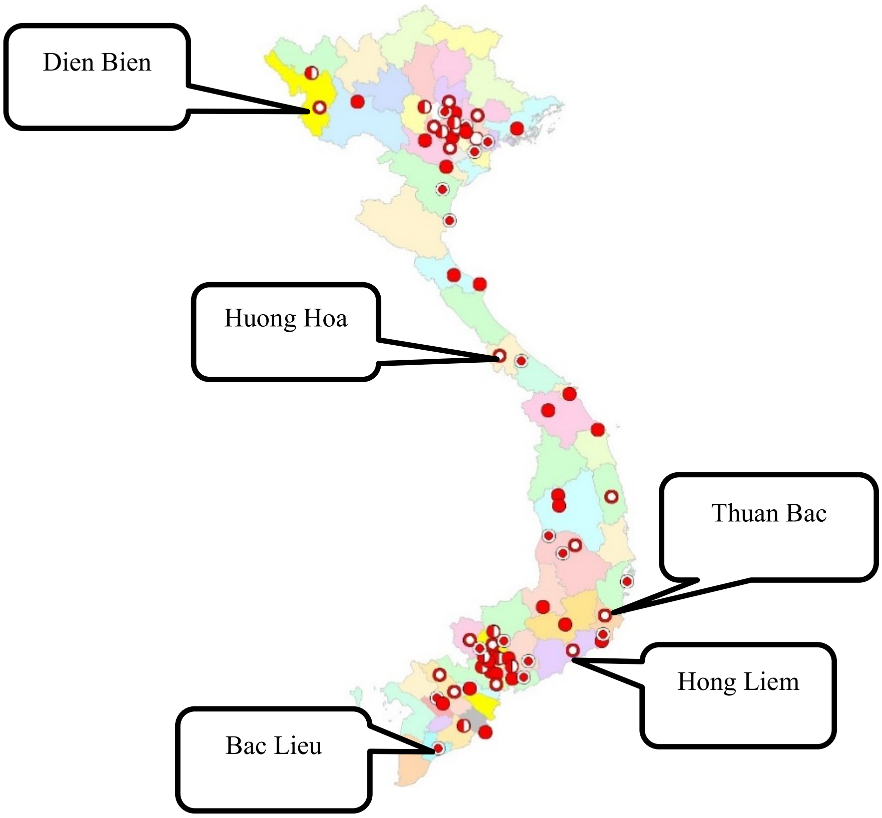

Figure 14. Some proposed location of 500kV substation to release power sources output.

Example: South Central HWS snapshot

For a detailed view, the report analyzes the transmission grid in South Central for the HWS snapshot (*C1 RE target* scenario). According to simulation results, there are some typical overloaded elements in region such as: Ninh Hoa – Nha Trang 220kV TL (overload 16%), Da Nhim – Thap Cham 220kV TL (overload 22%), Thap Cham – Thuan Nam 220kV TL (overload 68%), Phan Ri – Phan Thiets 220kV TL (5%), Ham Thuan – Phan Thiet 220kV TL (overload 24%), Ham Thuan Nam – Ham Tan (overload 10%).

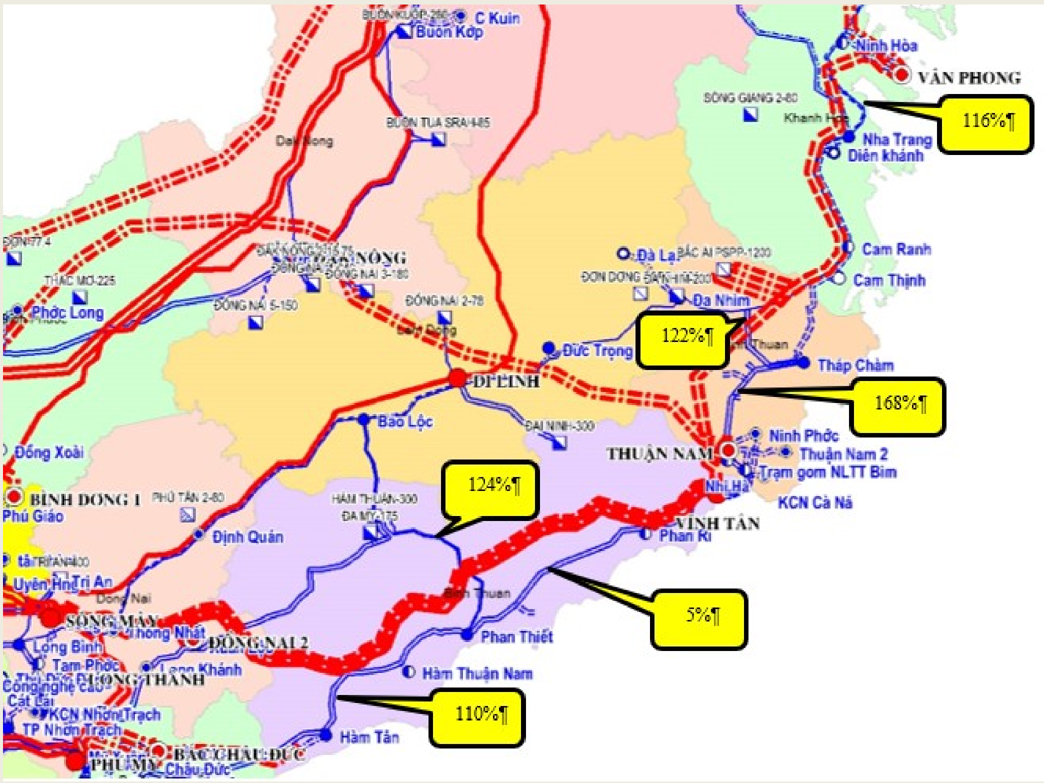

Figure 15 Overloaded elements in South Central in HWS snapshot for the C1 RE target scenario

In order to release wind and solar power in South Central, upgrading and extension of the transmission grid should be considered carefully in other studies. Some preliminary proposals are as follows:

- Proposal to build 2 of 500kV substations in South Central to gather wind and solar power in the Ninh Thuan anh Binh Thuan province to transmit to national power system (considering Thuan Bac and Hong Liem area).
- Proposal to build a 220kV switching substation in the Ninh Son area to reduce the load level of Da Nhim – Thap Cham 220kV TL and Thap Cham – Thuan Nam 220kV TL.
- Proposal to upgrade capacity limit of some transmission lines such as: Phan Ri – Phan Thiet 220kV TL, Phan Thiet – Ham Thuan 220kV TL, Da Nhim – Duc Trong – Di Linh 220kV TL.

In the N-1 contingency cases (N-1):

- All six regions have overloaded circuits when the other circuit fault (in case of double-circuit line). In these cases, it is recommended to improve the limit capacity by replacing with thermal resistant conductor or larger cross section conductor.
- Proposing to build the second circuit of current single-circuit lines having an important role in transmitting power sources in Viet Tri - Son La, Da Nhim - Duc Trong - Di Linh areas.

According to the simulation results, to meet the requirement of the N-1 criteria, it is necessary to reinforce about 890km line in North, about 370km line in North Central, about 20km line in Center Central, about 110km line in South Central, about 390km line in Highland and about 1300km line in South.

Estimated volume of grid work to connect renewable energy sources:

According to the calculations, more construction of the transmission grid is needed in order to connecting the power from renewable energy sources to the demand nodes, including: about 750MVA transformer and 34km line in Center Central; about 8000MVA transformer and 180km line in South Central; about 3500MVA transformer and 230km line in Highland; about 5500MVA transformer and 94km line in South. Due to the large concentration of renewable energy in Highland, South Central and South, as these areas have significant construction volumes compared to other regions.

The total estimated volume of grid works to be built for the *C1 RE target* scenario in comparison with PDP7R in the period 2020-2030 is summarized as follows:

Table 3. Estimated investment volume of grid works additional to PDP7R for *C1 RE target* scenario in the period 2020-2030.

Region	500kV transformer (MVA)	500kV line (km)	220kV transformer (MVA)	220kV line (km)
North	6300	390	0	2318
North Central	2700	0	0	382
Center Central	6300	40	750	58
Highland	9000	1748	3500	671
South Central	4500	790	8000	1747
South	7800	60	5500	1833
Total	**36600**	**3028**	**17750**	**7009**

7.2.2. *RE3 50 pct scenario*

Transmission interface:
Under normal operation conditions (N-0):

The two generation development scenarios result in different transmission trends in transmission interfaces. With HRD and LWS snapshots, the flow on interfaces in the *C1 RE target* and *RE3 50pct* scenarios does not change much. However, HF and HWS snapshots in the *RE3 50pct* scenario recorded a large amount of transmission power from Highlands through Center Central and North Central, respectively, to supply Northern load. The main reason is a strong development of renewable energy in the South, especially solar power. Balmorel results propose the construction of about 24000 MW of solar power in the South. Demand in the South is supplied mainly by regional solar power, so renewable energy sources in Highlands (also a strong development of renewable energy region) mainly transmit back to North.

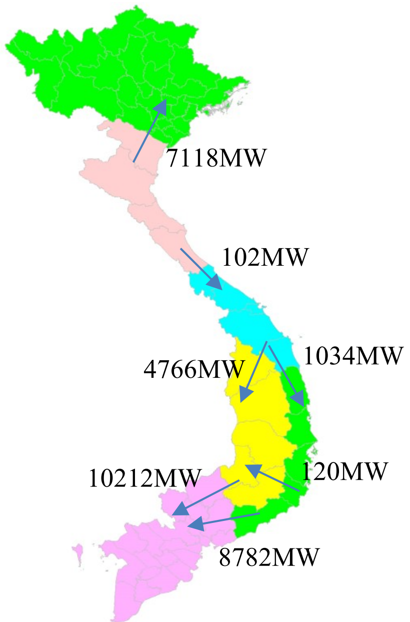

Figure 16. Flow on interfaces in *C1 RE target* scenario (HF snapshot).

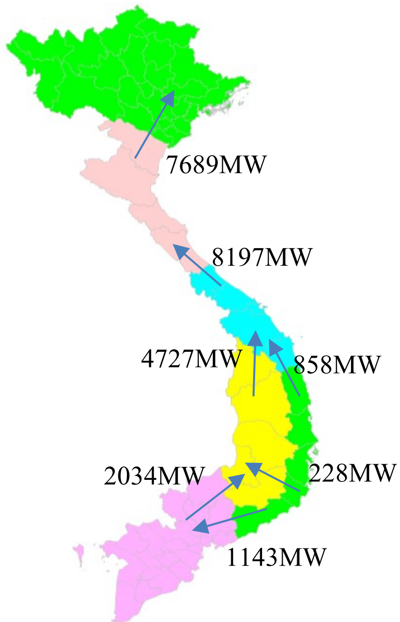

Figure 17. Flow on interfaces in *RE3 50pct* scenario (HF snapshot).

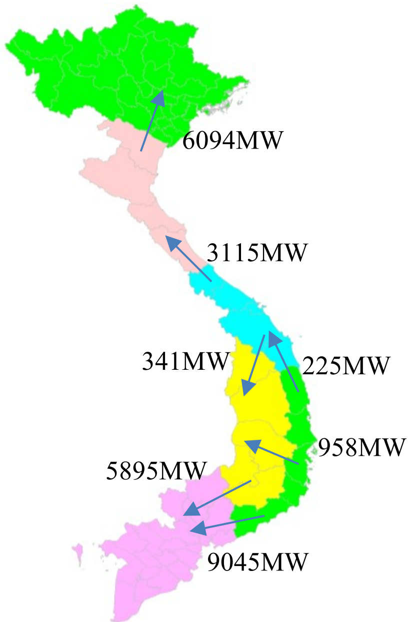

Figure 18. Flow on interfaces in *C1 RE target* scenario (HWS snapshot).

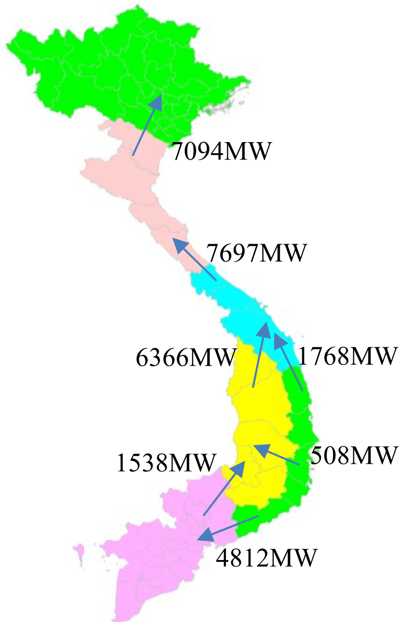

Figure 19. Flow on interfaces in *RE3 50pct* scenario (HWS snapshot).

Due to the large amount of transmission power from Highlands to North, the net transfer capacity of North Central - Center Central interface is not guaranteed in both HF and HWS snapshots. Geographically, this is a narrow area so building more transmission lines is difficult to implement. Therefore, it is recommended to consider building a direct HVDC transmission line from Highlands to North (about 900 - 1000km).

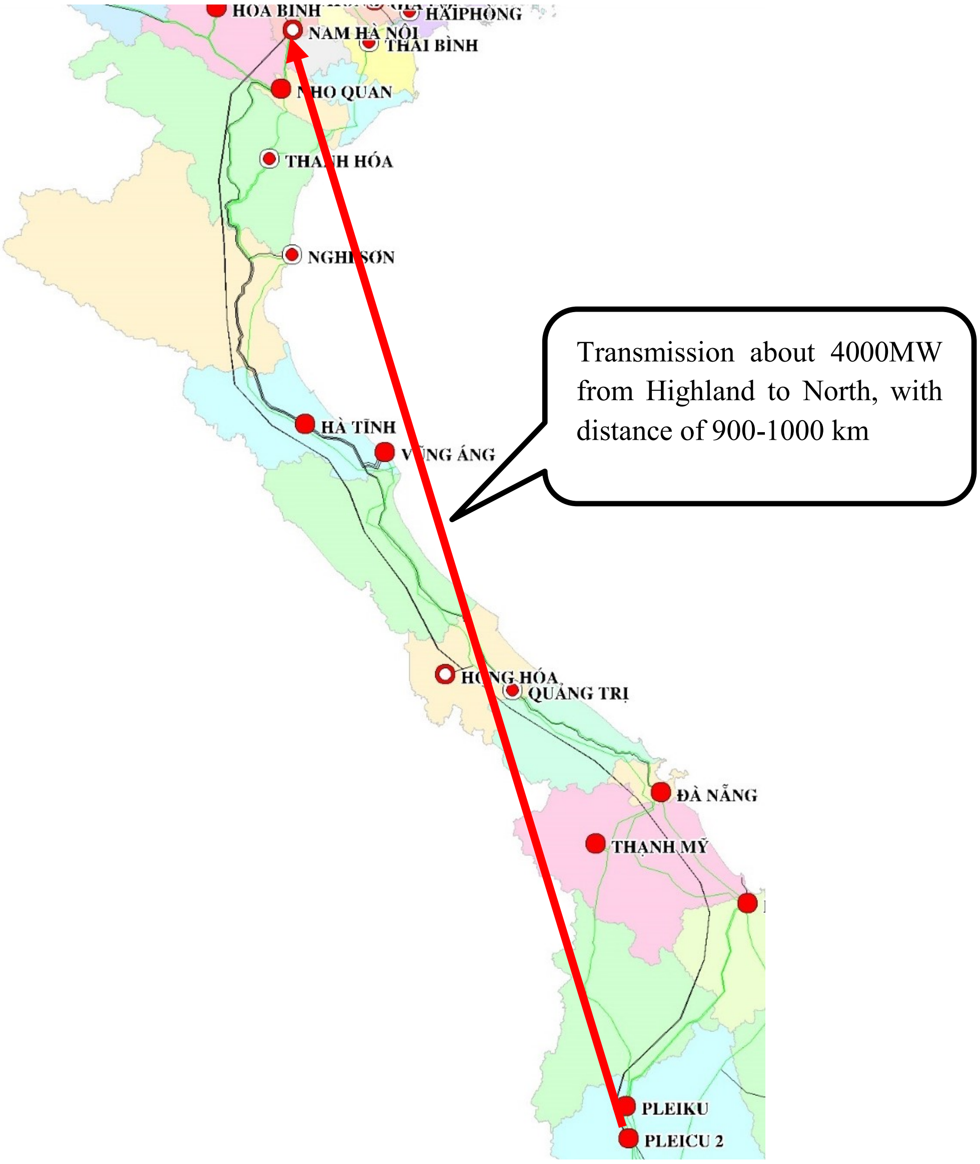

Figure 20. Solution to build transmission line directly from Highland to North.

In the N-1 contingency cases (N-1):

In order to ensure operation in N-1 contingency cases, Dong Hoi - Dong Ha 220kV transmission line connecting North Central - Center Central needs to be upgraded.

Internal transmission grid:
Under normal operation conditions (N-0):

- Grid reinforcement solutions for RE3 50pct scenario are inherited from C1 RE target scenario. Here, some areas need to build 500kV substations to gather power output such as Dien Bien, Huong Hoa, Dak Lak, Thuan Bac, Hong Liem, Bac Lieu.

- Considering strengthening the 500kV transmission lines to create circuit links in Hanoi load center area to receive additional electricity from North Central and Highland regions.

In the N-1 contingency cases (N-1):

Similar to the *C1 RE target* scenario, lines having overloaded circuits in case of other circuit fault need to be reinforced to improve limit capacity. In this scenario, it is necessary to reinforce about 915km line in North, about 410km line in North Central, about 265km line in Center Central, about 115km line in South Central, about 390km line in Highland and about 1450km line in South.

Estimated volume of grid work to connect renewable energy sources:

According to preliminary calculations, it is necessary to build 500/220 kV and 220/110 kV substations to collect renewable energy and transmit to national power system: about 1000 MVA transformer and 38km line in North; about 500MVA transformer and 40km line in North Central; about 750MVA transformer and 34km line in Center Central; about 8000MVA transformer and 180km line in South Central; about 6750MVA transformer and 272km line in Highland; about 7000MVA transformer and 218km line in the South.

Total estimated volume of grid works to be built for the *RE3 50pct* scenario in comparison with PDP7R in the period 2020-2030 is summarized as follows.

Table 4. Estimated investment volume of grid works additional to PDP7R for *RE3 50pct* scenario in the period 2020-2030.

Region	500kV transformer (MVA)	500kV line (km)	220kV transformer (MVA)	220kV line (km)
North	6300	3170	1000	2580
North Central	2700	0	500	691
Center Central	6300	40	750	322
Highland	9000	1748	6750	713
South Central	6300	971	8000	2033
South	7800	60	7000	2001
Total	**38400**	**5989**	**24000**	**8340**

7.3. The additional investment cost for transmission grid corresponding to the generation development scenarios

For estimating the investment cost, the unit price of lines and substations according to approved data in PDP7R [4] are used. In particular:

- Cost for 500kV line amounts to 0.9 million USD/km with capacity of about 2000MW.
- Cost for 220kV line amounts to 0.3 million USD/km with capacity of about 600MW.
- Cost for substation amounts to about 0.02 million USD/MVA.

From the results of the grid analysis, the estimated total investment cost for the transmission grid in the *C1 RE target* and *RE3 50pct* scenarios in the period 2020-2030 is summarized in Table 5, Table 6. These costs include both the internal grid costs and the reinforcements on the interfaces between regions.

Table 5. Total investment cost for the transmission grid in *C1 RE target* scenario in the period 2020-2030.

Region	Investment cost for PDP7R (mill USD)	Additional investment cost for C1 RE target scenario (mill USD)	Total investment cost for C1 RE target scenario (mill USD)
North	3068	797	3865
North Central	949	75	1024
Center Central	1195	170	1365
Highland	823	1922	2745
South Central	765	1459	2224
South	2773	533	3306
Total	**9572**	**4957**	**14529**

Table 6. Total investment cost for the transmission grid in *RE3 50pct* scenario in the period 2020-2030.

Region	Investment cost for PDP7R (mill USD)	Additional investment cost for RE3 50pct scenario (mill USD)	Total investment cost for RE3 50pct scenario (mill USD)
North	3068	3370	6438
North Central	949	128	1077
Center Central	1195	196	1391

Highland	823	1996	2819
South Central	765	1756	2521
South	2773	620	3393
Total	**9572**	**8066**	**17638**

The total investment cost for the transmission grid for the *C1 RE target* scenario and the *RE3 50pct* scenario increased significantly compared to PDP7R (with 150% and 185% respectively). Renewable energy sources are concentrated in South Central and Highlands, which are low-load area. Therefore, it is necessary to invest in the interface transmission grid. The scenario with high development of renewable energy sources (*RE3 50pct*) will cause RE sources to transmit over a great distance of 900-1000 km from Highlands to North, therefore investment cost for the transmission grid in the *RE3 50pct* scenario is higher than the *C1 RE target* scenario by about 20%. In general, the development of many renewable energy sources will save fuel costs and protect the environment. On the other hand, it could result in high investments in transmission grids.

The investment cost for the interface transmission grid accounts for about 30% of the total investment cost. Specifically, the investment cost for each interface is as follows.

Table 7. Investment cost for interfaces in the *C1 RE target* scenario in the period 2020-2030.

Interface		Investment cost for PDP7R (mill USD)	Additional investment cost for *C1 RE target* scenario (mill USD)	Total investment cost for *C1 RE target* scenario (mill USD)	Balmorel investment costs for C1 RE target (mill. USD)
North	North Central	333	0	333	964
North Central	Center Central	0	0	0	0
Center Central	Highland	298	0	298	240
Center Central	South Central	154	0	154	674
Highland	South	542	1210	1752	1328
South Central	South	182	802	984	674
Highland	South Central	220	69	289	0
Total		**1729**	**2081**	**3810**	**3880**

Table 8. Investment cost for interfaces in the *RE3 50pct* scenario in the period 2020-2030.

Interface		Investment cost for PDP7R (mill USD)	Additional investment cost for RE3 50pct scenario (mill USD)	Total investment cost for RE3 50pct scenario (mill USD)	Balmorel investment costs for RE3 50pct (mil. USD)
North	North Central	333	12	345	1039
North Central	Center Central	0	21	21	682
Center Central	Highland	298	0	298	240
Center Central	South Central	154	0	154	300
Highland	South	542	1210	1752	1211
South Central	South	182	802	984	346
Highland	South Central	220	69	289	0
North	Highland	0	2439	2439	2439
Total		**1729**	**4553**	**6282**	**3819**

Table 9. Transmission line investment capacity for interfaces in the *C1 RE target* scenario in the period 2020-2030.

Interface		Transmission line for PDP7R (MW)	Additional transmission line for C1 RE target scenario (MW)	Total transmission line for C1 RE target scenario (MW)	Balmorel transmission line for C1 RE target scenario (MW)
North	North Central	7034	0	7034	5355
North Central	Center Central	0	0	0	0
Center Central	Highland	1100	0	1100	1600
Center Central	South Central	1869	0	1869	3209
Highland	South	2200	5500	7700	7377
South Central	South	5082	4281	9363	4496
Highland	South Central	1408	899	2307	0
Total		**18693**	**10680**	**29373**	**22037**

Table 10. Transmission line investment for interfaces in the *RE3 50pct* scenario in the period 2020-2030.

Interface		Transmission line for PDP7R (MW)	Additional transmission line for RE3 50pct scenario (MW)	Total transmission line for RE3 50pct scenario (MW)	Balmorel transmission line for RE3 50pct scenario (MW)
North	North Central	7034	450	7484	5771
North Central	Center Central	0	537	537	3250
Center Central	Highland	1100	0	1100	1600
Center Central	South Central	1869	0	1869	1430
Highland	South	2200	5500	7700	6730
South Central	South	5082	4281	9363	2308
Highland	South Central	1408	899	2307	0
North	Highland	0	4000	4000	0
Total		**18693**	**15667**	**34360**	**21089**

As seen, compared to the investment volume of PDP7R, interface transmission grid will need to invest twice as much for the *C1 RE target* scenario and 3 times for the *RE3 50pct* scenario.

8. Conclusions

In this study, a detailed grid assessment of power system scenarios modelled in Balmorel has been performed in the model PSS/E to analyse the implications of increased power demand and higher RE shares on the transmission grid. The grid simulations in PSS/E covered critical snapshots for two milestone years, 2020 and 2030, as to test the viability of the generation and grid configuration found by the Balmorel least-cost optimization. For each of these snapshots, load levels and voltage requirements were tested and compared to the Vietnamese grid code. Both normal (N-0) operation conditions and (N-1) contingency cases have been considered.

For the *C1 RE target* scenario, some of the recommendations for safe grid operation include, e.g. a new 500kV substation in Highlands and additional 10 GW transmission line (three 500kV lines) to be able to transmit renewable power directly to the South East region. In the internal grid, some additional substations are suggested to support the system in the most congested nodes (such as in Dien Bien, Huonh Hoa, Bac Lieu, Hong Liem and Thuan Bac).

In the *RE3 50pct* scenario, the strong developments of solar generation in the South region increase the need for grid reinforcements. New solar generation in the Highland region is mostly transmitted to the demand center in the North region. The grid analysis results indicate that it could be worthwhile investing in a large HVDC transmission line directly from Highlands to North, due to the mountainous area between the two regions. Additional to the internal grid suggestions for the *C1 RE target scenario*, reinforcement of the grid around Hanoi would be needed. In total, the grid related costs (including transmission lines and substations) amount to 14.5 and 17.6 billion USD in the *C1 RE target* and *RE3 50pct* scenario respectively, for the period 2020-2030.

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